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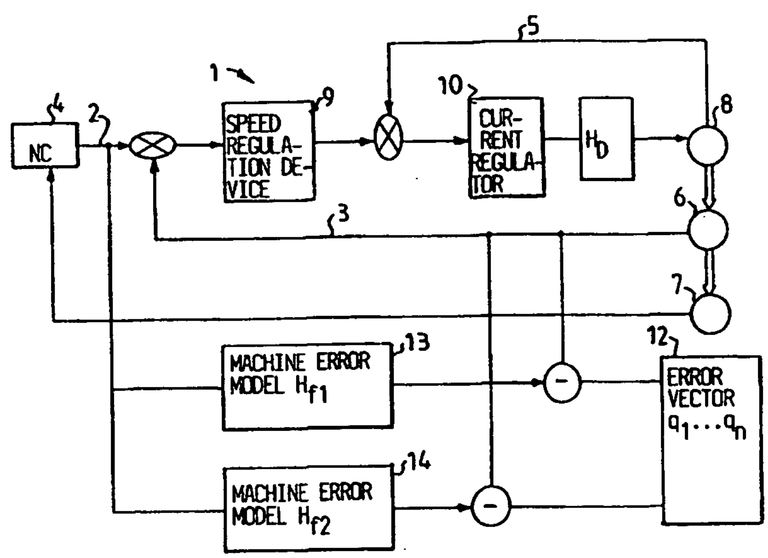

(57) Abstract

The invention relates to a method of analyzing the state of a device, such as a multi-operation machine, comprising the stages: feeding into the device an input signal in the form of a reference signal (2) which controls the device, and detecting an output signal (3, 5) from at least one component (6, 8) of the device, which output signal (3, 5) is dependent on how the device is controlled by the reference signal (2), creating a model (11, 13, 14) which represents a model output signal which corresponds to the function or a fault of the component (6, 8) forming part of the device, and comparing the model output signal with the output signal (3, 5) from the component (6, 8).

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METHOD TO DIAGNOSE AND DETECT TROUBLE IN A MACHINE

The present invention relates to a method of analyzing the state of a device according to the preamble of Patent Claim 1.

Devices, such as multi-operation machines of NC or CNC type, often work continuously over a period of time. In order to prevent the device breaking down or performing operations that are not planned, it is desirable to analyze the state of the device.

In a known method of analysis of the state of devices, use is made of sensors which are mounted at various measurement points of the device. In order to analyze the state of an element, for example a bearing in the device, a vibration sensor is mounted close to or on the bearing. Signals obtained from the sensor are compared with a desired value. If the value of the measured signal differs from the desired value, this is an indication that the bearing is worn and is in need of replacement.

The disadvantage of this known state analysis is that a number of sensors are required, which have to be mounted at different measurement points in the device. This results in the cost of the measurement equipment and thus the device becoming high. It is also complicated to mount the sensors on the various components of the device. The known state analysis is performed when the device is idling, that is to say outside the period of time when the device is working in continuous operation.

Another previously known method of detecting faults on a multi-operation machine at an early stage is roundness measurement according to the Renishaw method.

The machine is made to execute a circle with two of its axes, for example the x axis and the y axis. This circle is compared with a given reference circle and a deviation between them provides an indication of the state of the machine. The disadvantage of this method, however, is that the machine has to be stopped in order for it to be possible for the measurement to be carried out. It is also difficult to know from which component in the machine any fault detected is originating.

One object of the present invention is to produce a method of the type indicated in the introduction, which makes state analysis possible during operation of the device.

Another object is to produce a method of the type indicated in the introduction, which simplifies analysis of the state of the device.

A further object of the invention is to produce a method of the type indicated in the introduction, which requires a small number of sensors compared with the known art.

These objects are achieved by the invention by means of the method indicated in Patent Claim 1.

One reason why production stoppages often become time-consuming is long fault-finding times. By supplementing experience with these measurement methods, the fault-finding time can be reduced considerably in the case of emergency maintenance. This can be achieved by studying filtered data in the time plane. It is also possible to obtain an idea of the condition of the machines continuously during operation. The opportunity is then afforded of optimizing efforts aimed at preventative

maintenance. With refined analysis methods, it also follows that machine faults are detected earlier. This leads to reduced spare part costs because it is possible to plan purchasing in good time. With good knowledge about the state of the machines and with the possibility of adjusting machine parameters, wear can be reduced. This leads to improved product quality. Automatic fault-detection possibilities are further improved if models are used.

The invention is described in greater detail below with reference to the appended drawings showing exemplary embodiments, in which:

Fig. 1 shows a block diagram of a known multi-operation machine for controlling an axis,

Fig. 2 shows a block diagram of a model-based fault-detection system according to the invention, and

Fig. 3 shows a block diagram of a model-based fault-detection system according to the invention for detection of various faults;

Fig. 4 shows a diagram of the difference between model output signals;

Fig. 5 shows signals from a tachometer for the x axis and the y axis with a 90 degree phase displacement;

Fig. 6 shows a roundness plot of the tachometer and the reference;

Fig. 7 shows a roundness plot of the tachometer and the reference in the case of roundness measurement according to the invention;

Fig. 8a shows the tachometer signal and the reference signal in the case of quadrant turning for an x axis of a machine;

Fig. 8b shows the tachometer signal and the reference

signal in the case of quadrant turning for a y axis of a machine according to Fig. 8a, and

Fig. 9 shows a user system according to the invention.

Fig. 1 shows a block diagram of a known multi-operation machine for controlling an axis.

A large section of the engineering industry uses machines for cutting machining. Cutting machining means mainly milling, lathe turning and drilling. Multi-operation machines which perform drilling and milling are commonly found.

A multi-operation NC milling cutter is fundamentally made up of a spindle, a rotatable table and three axes x, y and z. The spindle moves in the y direction and the z direction while the table is moved in the x direction. The milling tool which performs the cutting machining is located in the spindle. The rotational speed of the spindle differs depending on factors such as the hardness of the material and the type of machining. The positioning of the axes is determined by the CNC computer in the NC machine. In most cases, the x axis and the y axis interact in the case of, for example, circular milling. The z axis then determines the depth of cut during machining. The programmer enters parameters for spindle revolution and positioning of the axes. The machine can operate with only a linear or a circular feed. The advantage of circular milling compared with lathe turning is that change-over time for moving the article between different machines is avoided. A multi-operation machine brings the milling tool for the next operation while the preceding operation is being performed.

There are a number of tools depending on the various

m ining operations such as d lling, face milling, circular milling, burring or reaming. The point of a multi-operation machine is to perform as much machining as possible without having to move the article between different machines. When the machine has finished machining, the finished article is replaced automatically by means of a robot.

Fig. 1 shows a block diagram of a known multi-operation machine for controlling an axis. In order to control the positioning of axes, use is made of a servo module 1 for each axis. Axis in this case means an x, y or z axis of the machine. The input signal to the servo module 1 is a reference signal 2 and the output signal is a tachometer signal 3. The purpose of the system is for the output signal to follow the reference signal 2 as accurately as possible. The reference signal 2 is provided by the CNC computer 4 in the NC machine. The tachometer signal 3 is a voltage which is proportional to the rotational speed of the axis. In order that the tachometer signal 3 follows the reference signal 2 as well as possible, use is also made of the actual current value 5 as an output signal from the driving motor 8 of the axis. The actual current value 5 is the current motor current required in order to drive an axis. The problem is generally called the servo problem, which comes from the Latin servus which means slave. The system is therefore to follow the reference signal 2 slavishly.

In Fig. 1, reference number 6 relates to a tachometer, reference number 7 relates to a measurement scale and reference number 8 relates to the motor for the axis.

From the reference to the tachometer 6, there is some form of dynamic, such as a ball screw, bearing etc.,

whi has been simplified to F in Fig. 1. The measurement scale 7 provides the current position of the axis to the NC machine 4. The block diagram according to Fig. 1 corresponds to one axis out of three. The same applies for the other axes.

Servo modules available on the market contain both a rotational speed regulator 9 and a current regulator 10. The function of the current regulator 10 differs slightly in different servo modules. Some make use of a pulse width modulator for each phase in order to distribute the correct current strength to the motor 8 of the servo module. Some regulators 9 are of the PI regulator type. The derivation function is not required because of the rapidity of the servo. The parameters of the current regulator 10 are adjusted ex factory and are usually not changed. It is, however, possible to influence the characteristics of the current regulator 10 via rotary potentiometers on certain servos. It is possible to adjust the gain of the rotational speed regulator 9.

The servo modules can be regarded as the heart of the machine. The servo receives the current values of current and rotational speed from the motors, the actual values. The servo then distributes the correct amount of current in the correct direction. In this way, the current operation can be influenced. What is important is how true the measurement values are. There are four measurement points of interest on the servo modules: the reference, the tachometer, the actual current value and the desired current value. On certain servos, there are ready-made measurement points. The signal from the tachometer passes through two filters in the servo but these are said to cut off above 10 kHz. The actual current values from the motors are

usually measured using Hall elements. These do not distort the signal appreciably below 100 kHz.

A number of different types of fault can occur during milling. A fault often arises when the axes are to change the direction of rotation. This may be due to the fact that there is backlash in the ball screw or that the ball screw is working sluggishly. If an axial bearing has been worn out, this may also give rise to backlash. A hole that is intended to be milled round can become oval, which may be due to a number of factors. The regulators have to be well tuned for correct roundness.

A tolerance can be set in the CNC computer 4 for how much slip is to be permitted in positioning. A great tolerance leads to it being difficult for the machine to follow the given reference. If too fast a working feed is used, an incorrect axis position often results. On certain machines, there is a balancing axis in the y direction. The aim is for it to be equally difficult for the motor to draw the axis upwards as downwards. The balancing axis is hydraulically controlled, so a constant pressure is required in the system in order for the balancing to be good. If the operator exerts excessive force in fixing the article in the fixture, the material yields. When the article is released after milling has been carried out, the material springs back again. A good way of checking the roundness is therefore to perform measurement on the article before it is removed from the fixture. The tool also gives rise to small faults because it is to some extent resilient.

The material may contain stresses and the hardness may differ. If acceptable quality has not been achieved on

the machined article, the machine in question must be investigated in order to establish why the quality requirements have not been met. The tolerance for acceptable quality is often two hundredths of a millimetre.

According to the present invention, the way in which the reference value (the desired value), the tachometer feedback (actual value), the desired current value and the actual current value respond during operation of the NC machine is studied, so that a picture is obtained of inter alia the following points:

- mechanical wear on machine elements;
- changes in motors and servos, such as their regulating accuracy;
- measurement system, such as its positioning accuracy.

Taking this as the starting point, possibilities for reducing the fault-finding time can be established. The method provides possibilities for improving preventative maintenance. With model-based detection, the possibility of automatically obtaining a warning in the event of a machine fault is also provided.

Fig. 2 shows a block diagram of a model-based fault detection system according to the invention.

With models 11 of functioning and non-functioning machines, the possibility is afforded of having automatic monitoring of the machines. Use is then made of a level detector 12.

The changes that give rise to a regulating fault can be detected. If the model 11 corresponds to a fault-free

machine, a change detected by the level detector 12 signifies a possible machine fault. As the multi-operation machine has a number of feedback loops, it is not possible to detect all faults using the same model 11. If the tachometer response follows the reference, no difference is obtained in the actual output signal and the model output signal. Compensation then takes place in the outer loop from the measurement sensor to the NC. Components in Fig. 2 which correspond to components in Fig. 1 have the same reference numbers.

Fig. 3 shows a block diagram of a model-based fault-detection system according to the invention for detection of faults.

With the invention, we have shown that it is possible to identify one type of fault on a faulty machine. The possibility then exists of going further with a greater number of models in order to detect different types of fault.

Fig. 3 shows how two different machine fault models 13, 14 are compared with the output signal 3 from the tachometer 6 of the axis in question. If a fault occurs in a component on the axis in question of the machine, this fault will be compared with the machine fault model 13, 14. The model 13, 14 that corresponds most closely to the machine fault will give the smallest output signal difference. It is then possible to identify specifically the fault that is present in the machine. Components in Fig. 3 which correspond to components in Figs 1 and 2 have the same reference numbers. Fig. 3 shows two machine fault models 13, 14. It is obvious that use can be made of more than two fault models. A fault model is suitably produced for every possible fault and is compared with output

signals from the machine during operation. The model accuracy is of absolutely crucial significance. In order to justify fault isolation using models, it is of interest to study how much the models differ. A signal generator can be used to generate the reference signal. The model output signals are produced by filtering the input signal in an analysis unit, such as Matlab. The filter parameters are determined by the model parameters that the identification provides. Fig. 4 shows the output signal difference.

The difference between the output signals is great in this case. While the amplitude of the output signal does not exceed ± 1 V, it can be seen that the difference exceeds ± 0.5 V. This difference can make level detection possible in order that it is possible to distinguish between different faults using models. It should be mentioned, however, that the difference becomes smaller when a slow input signal is used. But this is the way it is in practice too, of course. The faults that occur on the machines are often not obvious in the case of slow changes. If the intention is to use models in order to distinguish between faults, this should not be attempted with any minor faults. In that case, the fault gets lost in the inaccuracy of the model. There is a good starting position in those machines provided with a Bosch servo. In a quick comparison between the model of the z axis 46314 and the y axis 46325, the latter was 10 times better. However, this could be due to the fact that the z axis 46314 is not functioning satisfactorily. In such a case, an illustration is provided of two models of different degrees of the same fault.

The method of analyzing the state of a multi-operation machine comprises the following stages: an input signal

in the form of a reference signal is fed into the machine. This input signal controls the machine in the desired manner. Subsequently, an output signal from the machine is detected. This output signal is emitted from a component of the machine. The output signal is dependent on how the device is controlled by the reference signal fed in. In order for it to be possible to analyze the state of the machine, a model is created, which represents a model output signal which corresponds to a function or a fault of the component forming part of the device. When the model output signal represents a fault, the model output signal is compared with the output signal from the component. If the level of the model output signal corresponds to or differs little from the level of the output signal, this is a sign that a fault has occurred or will occur in the machine.

The output signal preferably corresponds to the actual signal from a tachometer which senses a movement from a ball screw, an axis or the like on the machine. If, for example, a bearing for a driving axis has broken down, the broken-down bearing gives rise to a characteristic fault signal. This characteristic fault signal is then emitted by the tachometer 6 of the machine in the form of an output signal 3 which is detected and compared with the model 13, 14 that has been created. The fault does not therefore have to have occurred in the tachometer 6 of the machine but in an element, such as a bearing, a fault in which is represented by the tachometer 6 of the machine. The advantage of creating a model 13, 14 which represents a fault in a component of the machine is that individual components of the machine can be detected when they are break down because a model can be created for each component. The output signal can also correspond to the actual signal

fro motor current which is required to drive an axis of the machine.

The theoretical background of the invention will be explained below..

In order to separate the signal of interest from noise, frequency-selective filters can be used. Different selections of filter depend on the requirements with regard to the slope of the filter in the transition band and whether ripple is permitted. The advantage of filters that permit ripple is that they are steeper in the transition band and a lower filter degree number can thus be selected. With low filter degree numbers, the poles do not end up so close to the unit circle, which results in transients decaying more quickly. It is therefore best to select as low a degree number as possible for filters on the basis of the requirements that are made for the filtered signal. The sampling rate can be a problem. It is desirable to start by sampling rapidly and then gradually reduce the sampling rate to around 10 times the bandwidth of the machine.

A very important aspect of manufacturing various articles is that the circular milling is indeed round. One objective of the invention is to replace or complement the Renishaw measurement method used today. Renishaw measurement is carried out in the following way. A magnet is attached to a fixture, and, between the magnet and the fixture, there is a probe which measures the distance. In the NC computer, there is a program which performs a circular movement with a radius which may be around 150 mm. In this case, it is only the x axis and the y axis that move. When one revolution has been carried out and the data have been processed, a picture is obtained of how the machine has

performed the circular movement. All deviations from the radius will appear clearly because the accuracy of the deviation can be selected. This method functions quite well but it is necessary to stop production in order to carry it out.

According to the invention, the movement of the x axis is plotted against the movement of the y axis as shown in Fig. 5. As these signals have a phase displacement of 90 degrees, a circle is formed in the case of circular milling. If there is a deviation in roundness, this will appear in the circle from the tachometer signal according to Fig. 6.

Fig. 7 shows a roundness plot of tachometer and reference, which has been made on a machine. It is clearly visible here that the circles for reference and tachometer are not centred at the origin. There is therefore a no-load voltage which is not 0 V. The axes want to drift off but are held back via the reference so as to maintain the correct position. This is a fault which can be detected using the method for roundness measurement according to the invention.

Figures 8a and 8b show the reference signal and the tachometer signal for the x axis and the y axis respectively on enlarged scale in the case of quadrant turning. The measurement has been performed during operation in circular milling. A defect in the case of turning in the x direction is clearly visible here, although it is absent in the y direction. That this is sluggishness is revealed by the fact that the reference responds at the same time as the tachometer. If it had been play, the tachometer signal would have responded after the reference signal.

By rying out a comparison between the currents on the x axis and the y axis, it can be seen that a great amount of current is consumed in turning in the x direction and if a comparison is made with the current in the y direction. It is then possible to conclude that operation is sluggish in the case of turning on the x axis.

Faults that can be detected on a multi-operation machine using the method according to the invention are, for example:

- faultily adjusted regulators (unnecessary wear, poorer quality);
- sluggishness in the axes as well as play in the case of axis turns (can be differentiated);
- servo faults (non-linear phenomenon in one case);
- positioning problems and measurement scale faults (constant faulty regulation);
- imbalance (results in asymmetric turns);
- offset faults (displaced circle).

For continuous control of a group of machines, the equipment shown in Fig. 9 can be used. There are a number of different proposed solutions. One possible alternative is to make use of a BNC switch for a group of machines, which is connected to an SCXI chassis. For a larger group of machines, use is made of a measurement collection computer which can be controlled via a network.

A number of measurement times for each machine are selected for measurement collection during operation. Suitable trigger levels can be set using measurement collection programs. After the data have been filtered,

it is possible, by means of a model for the machine in question, to compare the actual output signal with the model output signal.

A model that lends itself well to implementing the method according to the present invention is the so-called ARX model. The way this model is obtained will be explained in general terms below. It is suitable to study standard models since these can handle different cases of system dynamics. This is a good method when it is not possible to investigate all the physical relationships. As data are collected in sampled form, use is made of time-discrete models.

$$y(t)=\eta(t) + \omega(t)$$

Here, $\omega(t)$ designates interference in the output signal and $\eta(t)$ the interference-free output signal which can be written as

$$\eta(t)+f_1\eta(t-1)+\ldots+f_{nf}\eta(t-nf)=b_1u(t-nk)+\ldots+b_{nb}u(t-(nb+nk-1))$$

There is consequently a delay of nk samples. The sampling interval T is then assumed to be a time unit. This can be written with the transfer operator as below.

$$\eta(t)=G(q,\theta)u(t)$$

Where $G(q,\theta)$ is a rational function of the displacement operator q. θ is a vector containing the parameters of the transfer operator. (The transfer function is obtained by exchanging q for z).

$$G(q,\theta)=\frac{B(q)}{F(q)}=\frac{b_1q^{-nk}+b_2q^{-nk-1}+\ldots+b_{nb}q^{-nk-nb+1}}{1+f_1q^{-1}+\ldots+f_{nf}q^{-nf}}$$

In the same way, the interference term can be written

$$\omega(t) = H(q,\theta)e(t)$$

th

$$H(q,\theta) = \frac{C(q)}{D(q)} = \frac{1 + c_1 q^{-1} + \ldots + c_{nc} q^{-nc}}{1 + d_1 q^{-1} + \ldots + d_{nd} q^{-nd}}$$

where $e(t)$ is white noise. The time-discrete model can now be summarized as

$$y(t) = G(q,\theta)u(t) + H(q,\theta)e(t)$$

The parameter vector θ includes the coefficients b_i, c_i, d_i and f_i in the transfer operator which are adapted to the data after the structural parameters n_b, n_c, n_d, n_f and n_k have been selected, which determine the model order and the time delay.

Then the denominators of G and H are made to coincide

$$F(q) = D(q) = A(q) = 1 \div a_1 q^{-1} + \ldots + a_{na} a^{-na}$$

By extending with $A(q)$

$$A(q)y(t) = B(q)u(t) + C(q)e(t)$$

is obtained.

A ready-made model called the *ARMAX model* has now been obtained. A special case of this is obtained when $C(q) \equiv 1$, that is to say $n_c = 0$.

$$A(q)y(t) = B(q)u(t) + e(t)$$

This model is called the *ARX model*. The name comes in part from the fact that $A(q)y(t)$ represents an AutoRegression. The ARX model is a relatively simple model which will be understood by the person skilled in the art.

Prediction in the ARX case is given by

$$\hat{y}(t|\theta) = -a_1 y(t-1) - \ldots - a_{na} y(t-na) + b_1 u(t-nk) + b_{nb} u(t-nk-nb-1)$$

that is to say what the output signal is assessed to be based on measurement values and previous values of the output signal. In the identification tool Ident in Matlab, use is made of the syntax $ARXn_an_bn_k$.

At each time *t*, it is possible to evaluate how good this prediction was by calculating the *prediction error*

$$\varepsilon(t,\theta) = y(t) - \hat{y}(t|\theta)$$

The error variance is represented by

$$E\left[\varepsilon^2(t,\theta)\right] = \bar{V}(\theta)$$

The coefficients in the parameter vector θ are obtained by minimizing $V(\theta)$

$$V(\theta) = \frac{1}{N}\sum \varepsilon(t,\theta)^2$$

with respect to θ.

It can be shown that the variance error becomes smaller as noise is reduced and the amount of measurement data is increased, which is self-evident. The relationships even become proportional if it is assumed that the *bias error* (the model structure error) is zero and it is also assumed that there is a parameter vector θ which gives a prediction error ε which is white noise. The variance error gives a good appreciation of the quality of the model.

Tests have shown that the model ARX441 produces a good result when implementing the method according to the invention.

The thod has been described as referred exemplary embodiment for analyzing the state of a multi-operation machine. However, the invention is not limited to application to multi-operation machines. The method can, for example, be used on any piece of equipment, such as a wheeled loader, a dumper or another contract machine.

Patent Claims

1. Method of analyzing the state of a device comprising the stages: feeding into the device an input signal in the form of a reference signal (2) which controls the device, and detecting an output signal (3, 5) from at least one component (6, 8) of the device, which output signal (3, 5) is dependent on how the device is controlled by the reference signal (2), characterized by creating a model (11) which represents a model output signal which corresponds to the function of the component (6, 8) forming part of the device, and by comparing the model output signal with the output signal (3, 5) from the component (6, 8).

2. Method of analyzing the state of a device, comprising the stages: feeding into the device an input signal in the form of a reference signal (2) which controls the device, and detecting an output signal (3, 5) from a component (6, 8) of the device, which output signal (3, 5) is dependent on how the device is controlled by the reference signal (2), characterized by creating a model (13, 14) which represents a model output signal which corresponds to a fault of the component (6, 8) forming part of the device, and by comparing the model output signal with the output signal (3, 5) from the component (6, 8).

3. Method according to Claim 1 or 2, characterized by determining the difference between the model output signal and the output signal (3, 5) from the component (6, 8) by means of a level detector (12).

4. Method according to Claim 1 or 2, characterized by creating a number of models (11, 13, 14) which represent model output signals for a number of

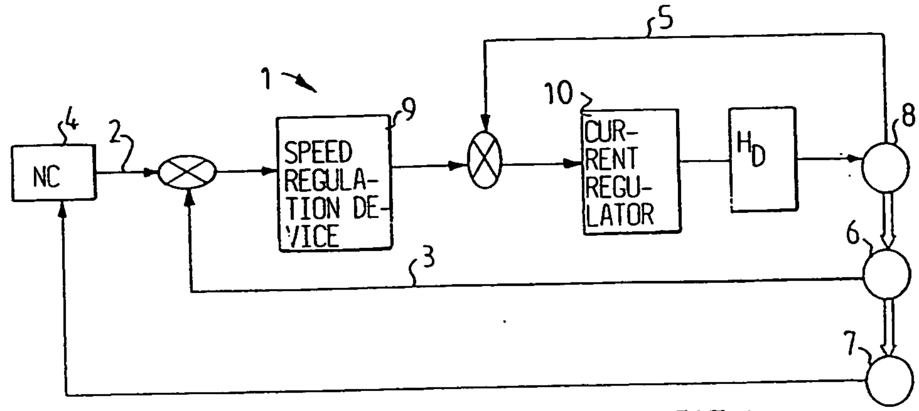
components (6, 8) forming part of the device, which model output signals are compared with the output signal (3, 5) from each respective component (6, 8).

5. Method according to any one of the preceding claims, characterized in that the model (11, 13, 14) consists of an ARX model.

6. Method according to any one of the preceding claims, characterized in that the output signal represents a tachometer signal (3).

7. Method according to any one of Claims 1-5, characterized in that the output signal represents a current signal (5) emitted from the component.

8. Method according to any one of the preceding claims, characterized in that the device consists of a multi-operation machine.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SPEED REGULATION DEVICE
9
CURRENT REGULATOR
10
H_D
5
8
6
3
7

FIG.1

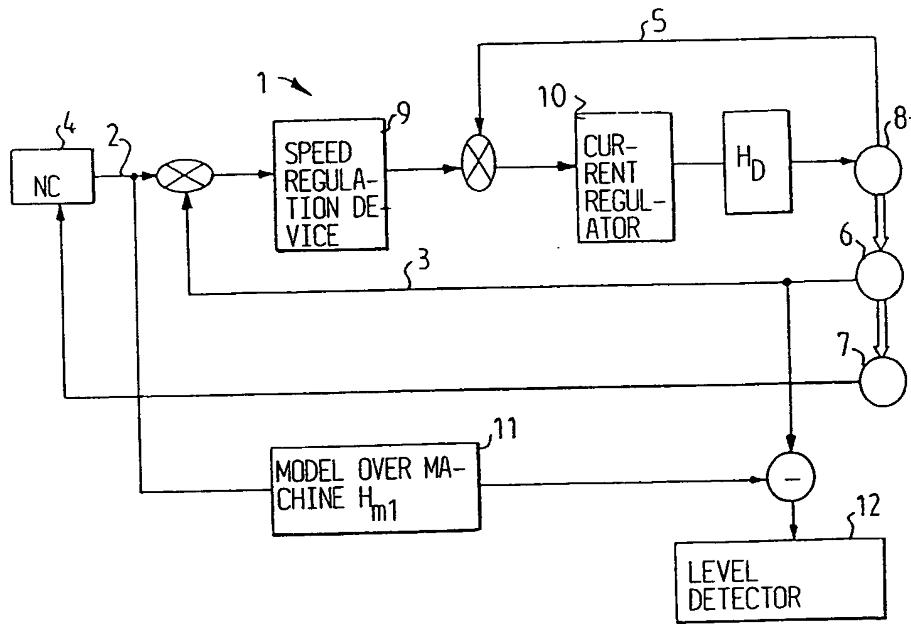

1
NC
4
2
SPEED REGULATION DEVICE
9
CURRENT REGULATOR
10
H_D
5
8
6
3
7
MODEL OVER MACHINE H_{m1}
11
–
LEVEL DETECTOR
12

FIG. 2

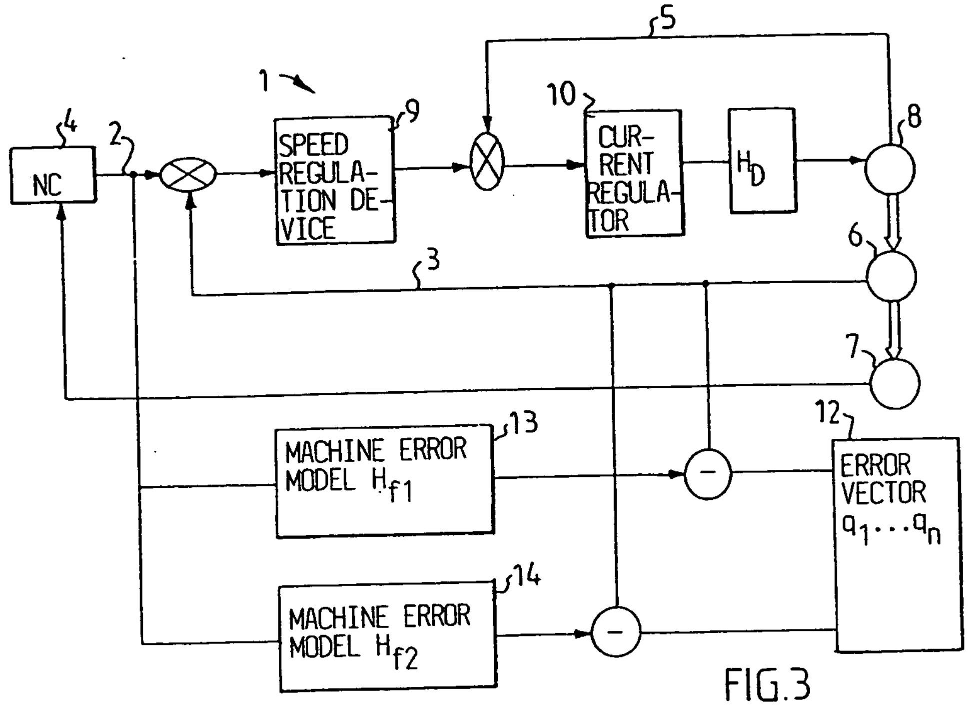

1
NC
4
2
SPEED REGULATION DEVICE
9
5
10
CURRENT REGULATOR
H_D
8
6
3
7
MACHINE ERROR MODEL H_{f1}
13
12
ERROR VECTOR $q_1 \dots q_n$
MACHINE ERROR MODEL H_{f2}
14

FIG.3

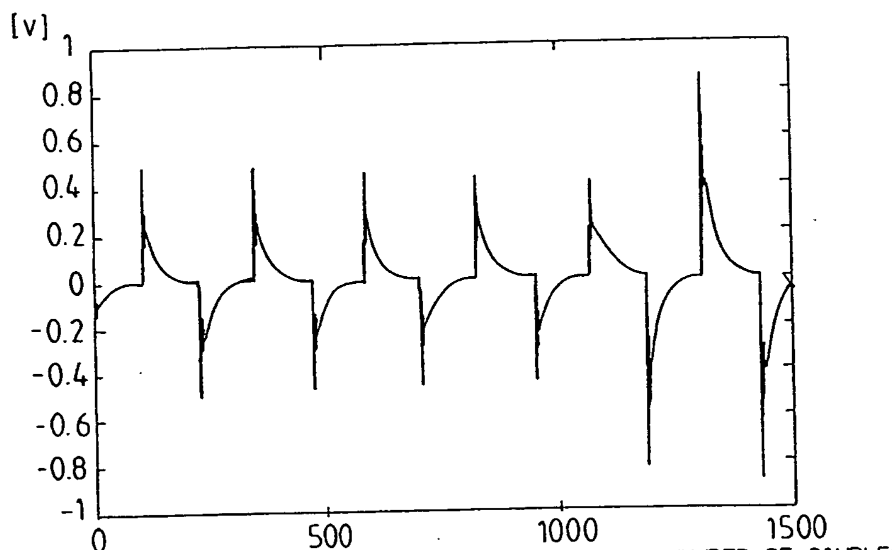

[v]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
500
1000
1500
NUMBER OF SAMPLES

FIG.4

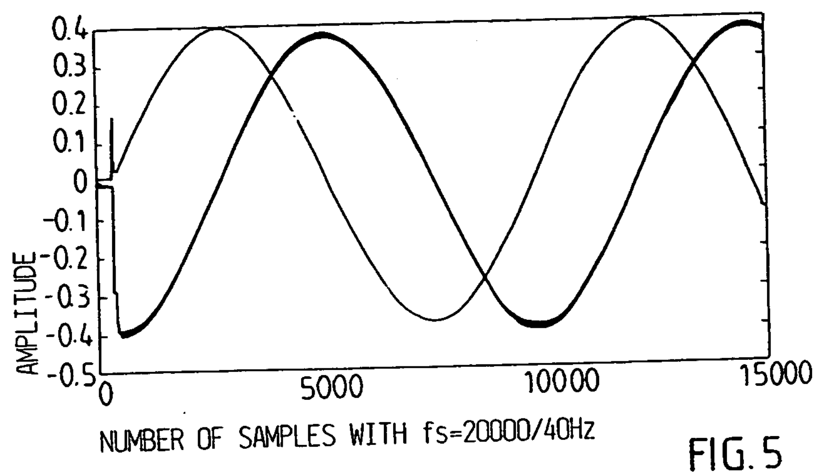

0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
AMPLITUDE
0
5000
10000
15000
NUMBER OF SAMPLES WITH fs=20000/40Hz

FIG. 5

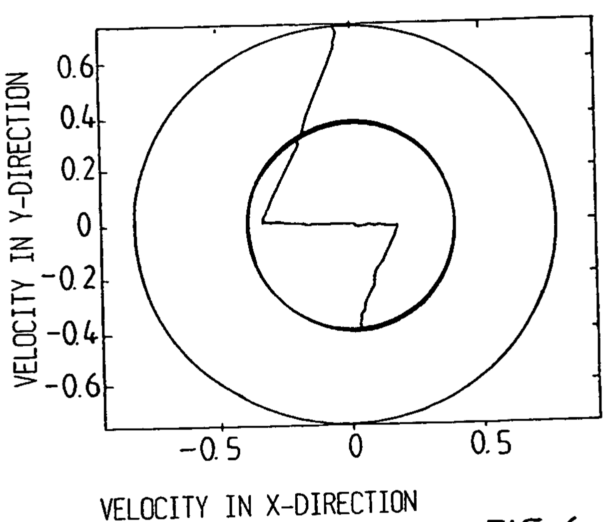

0.6
0.4
0.2
0
-0.2
-0.4
-0.6
VELOCITY IN Y-DIRECTION
-0.5
0
0.5
VELOCITY IN X-DIRECTION

FIG. 6

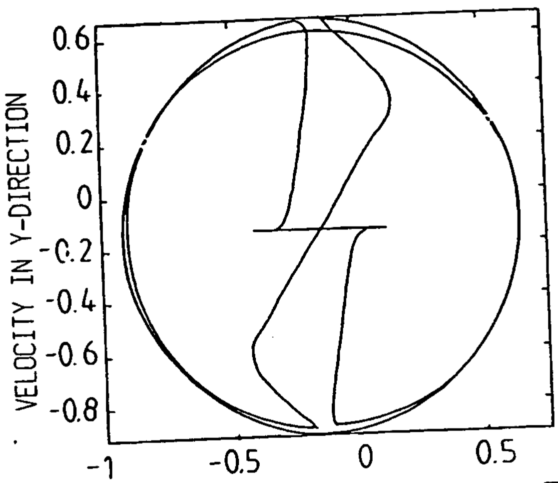


FIG.7

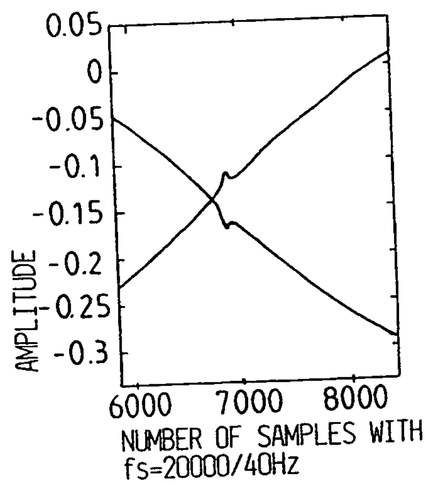


FIG. 8a

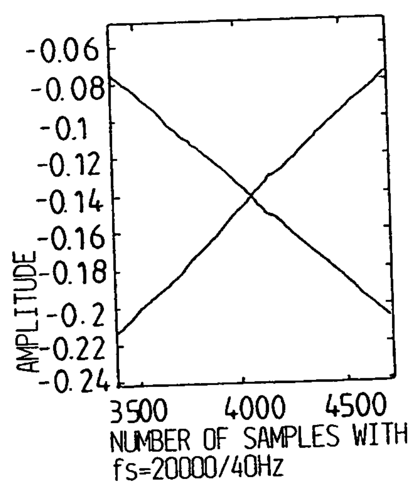


FIG. 8b

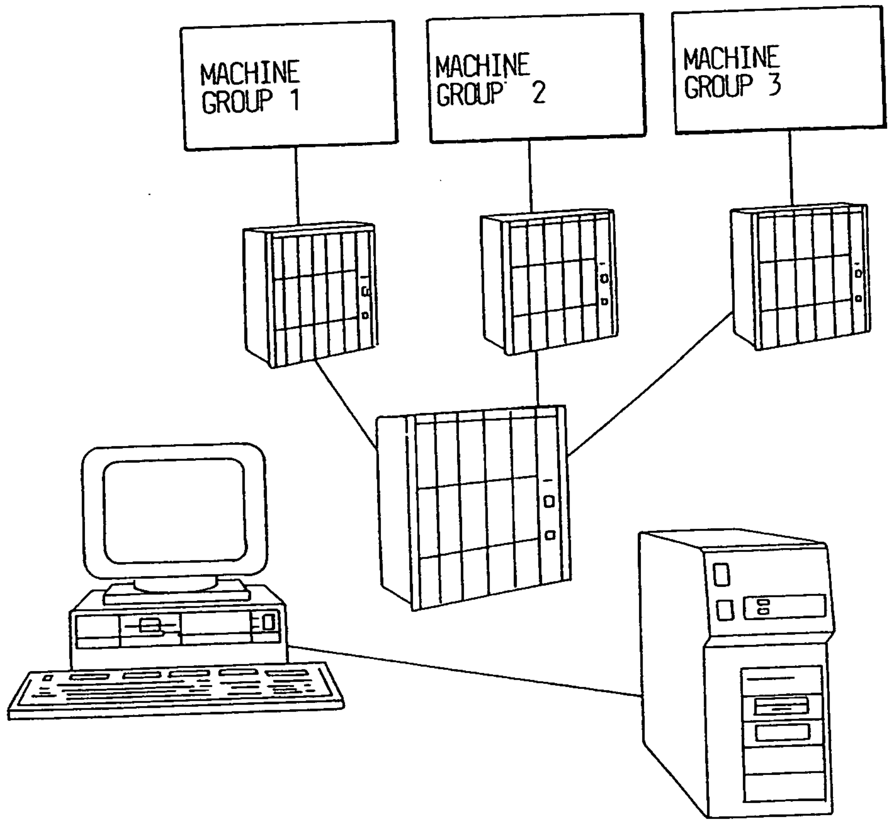


FIG.9

RNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02363

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G05B 23/02, G05B 17/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5465321 A (PADHRAIC J. SMYTH), 7 November 1995 (07.11.95), column 3, line 29 - column 5, line 25; column 17, line 40, figure 1	1-8
	--	
X	FR 2528191 (UNITED TECHNOLOGIES CORPORATION), 9 December 1983 (09.12.83), page 1, line 5 - line 16; page 1, line 33 - page 2, line 3, figure 1	1-4,6-8
	--	
X	US 4213175 A (NOBUO KURIHARA), 15 July 1980 (15.07.80), column 16, line 31 - column 17, line 2, abstract	1-4,6-8
	--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 March 1999	26 -03- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Sylvain Dunand Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02363

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

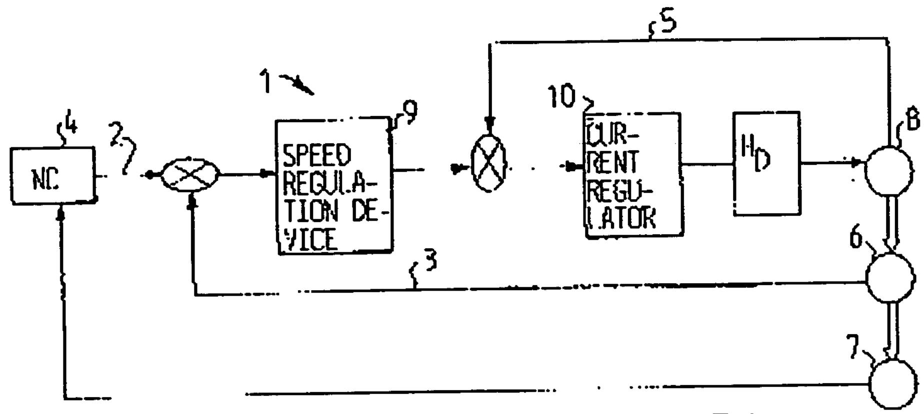
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	Jonny Alexandersson Analysmetoder för bearbetningsmaskiner Department of Electrical Engineering Linköpings University 1997-12-19 Reg nr: LiTH-ISY-EX-1841 --	1-8
A	US 5309379 A (KEITH C. RAWLINGS ET AL), 3 May 1994 (03.05.94) -- --------	1-8

INTERNATIONAL SEARCH REPORT
Information on patent family members

02/03/99

International application No.
PCT/SE 98/02363

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5465321 A	07/11/95	NONE	
FR 2528191	09/12/83	BE 896942 A	03/10/83
		DE 3319983 A,C	08/12/83
		DK 163843 B,C	06/04/92
		DK 256183 A	08/12/83
		GB 2121562 A,B	21/12/83
		GR 78808 A	02/10/84
		JP 1741328 C	15/03/93
		JP 4025565 B	01/05/92
		JP 59002111 A	07/01/84
		NL 191393 B,C	01/02/95
		NL 8301992 A	02/01/84
		US 4509110 A	02/04/85
US 4213175 A	15/07/80	JP 1371634 C	07/04/87
		JP 54013883 A	01/02/79
US 5309379 A	03/05/94	AU 4950990 A	05/09/90
		DE 69010193 D,T	13/10/94
		EP 0457783 A,B	27/11/91
		SE 0457783 T3	
		ES 2055418 T	16/08/94
		JP 4503272 T	11/06/92
		WO 9009644 A	23/08/90
		GB 2239634 A	10/07/91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1
10
4
2
9
8
NC
SPEED REGULATION DEVICE
CURRENT REGULATOR
H_D
6
3
7

FIG.1

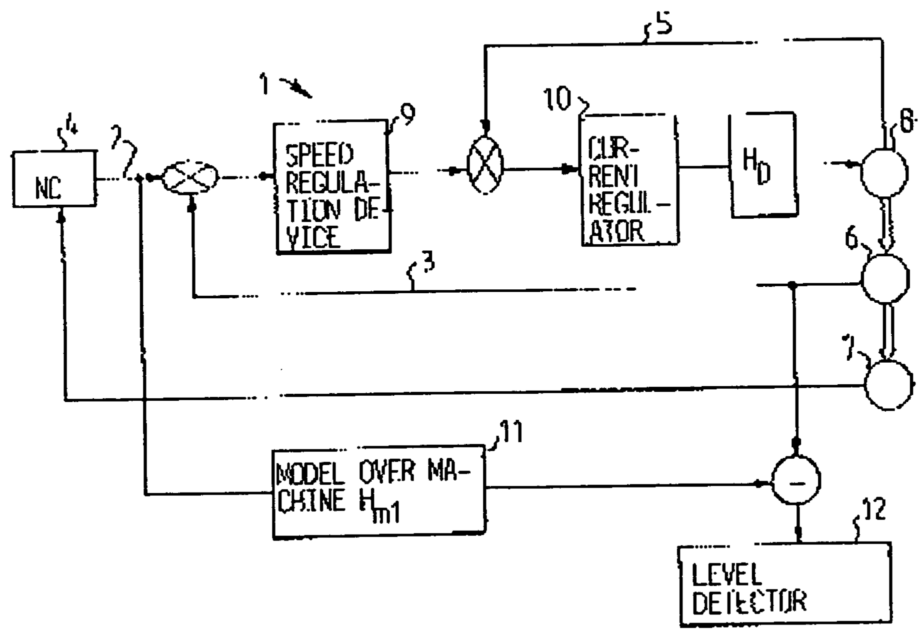
5
1
10
4
2
9
8
NC
SPEED REGULATION DEVICE
CURRENT REGULATOR
H_D
6
3
7
11
MODEL OVER MACHINE H_{m1}
12
LEVEL DETECTOR

FIG. 2

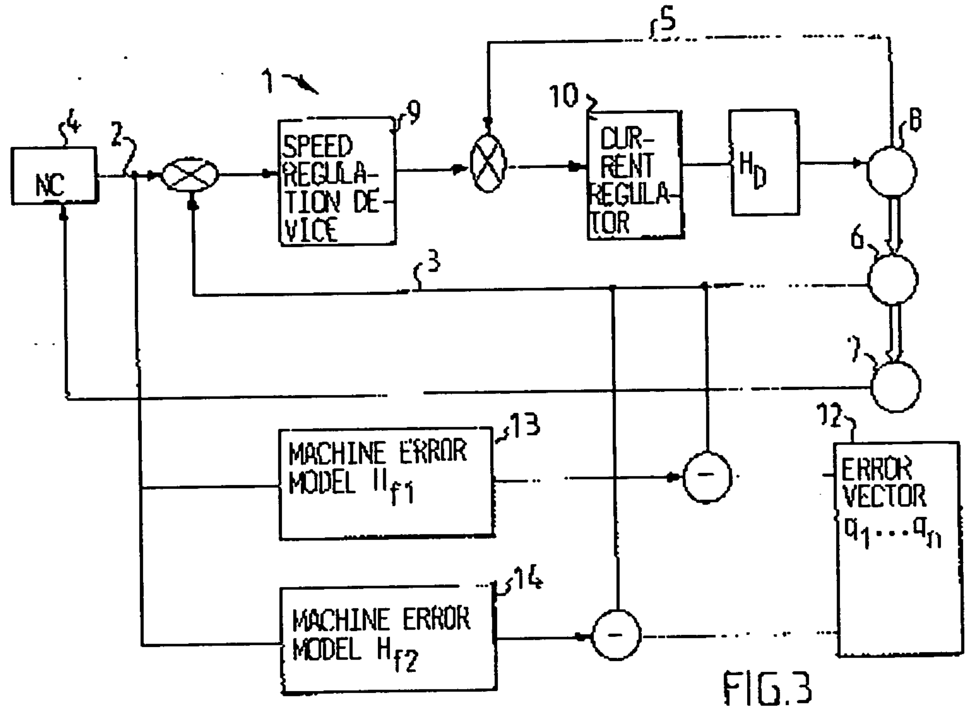
1
NC
4
2
SPEED REGULATION DEVICE
9
5
10
CURRENT REGULATOR
H_D
8
6
3
7
MACHINE ERROR MODEL H_{f1}
13
12
ERROR VECTOR $q_1 \ldots q_n$
MACHINE ERROR MODEL H_{f2}
14

FIG.3

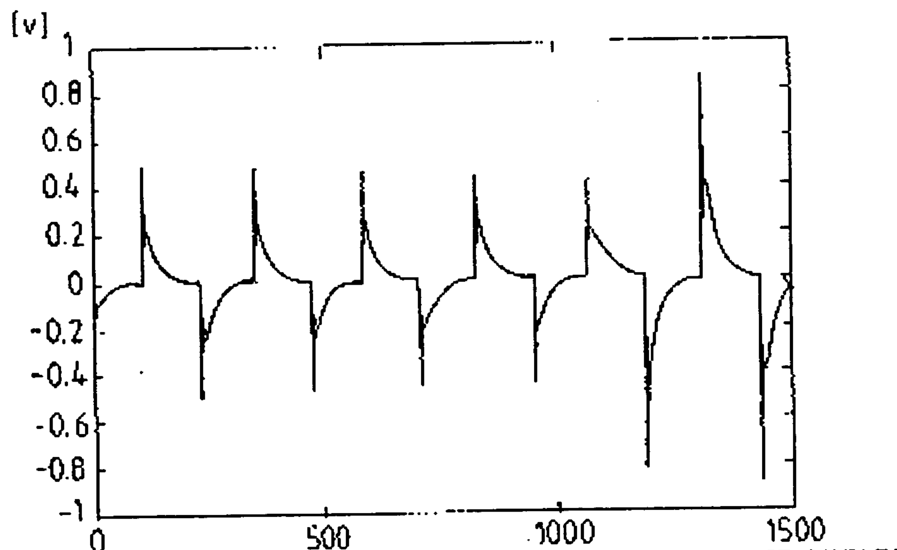
[v]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
500
1000
1500
NUMBER OF SAMPLES

FIG.4

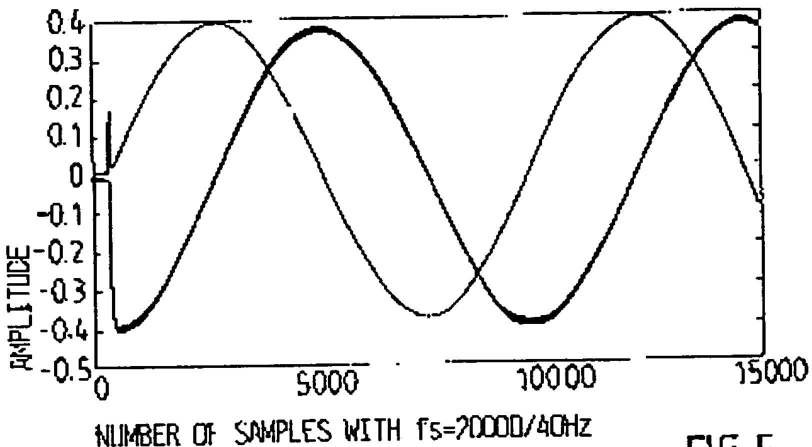
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
AMPLITUDE
0
5000
10000
15000
NUMBER OF SAMPLES WITH fs=20000/40Hz

FIG.5

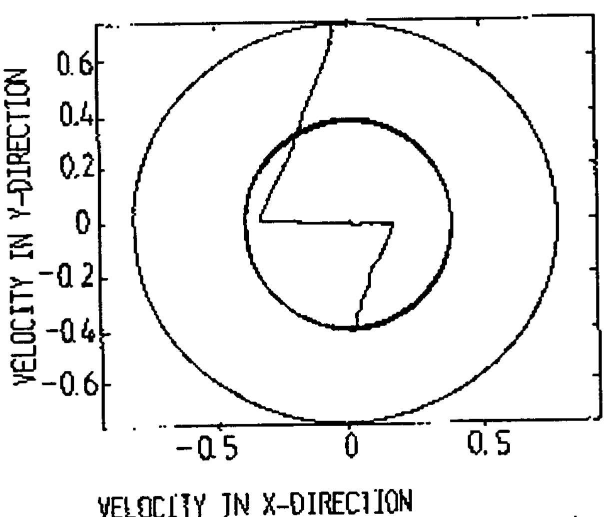
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
VELOCITY IN Y-DIRECTION
-0.5
0
0.5
VELOCITY IN X-DIRECTION

FIG.6

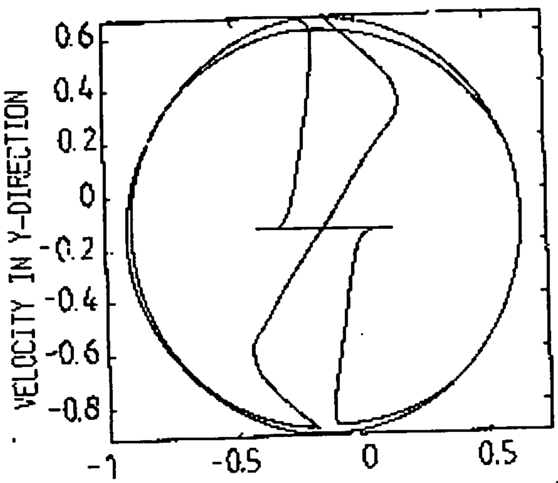

FIG.7

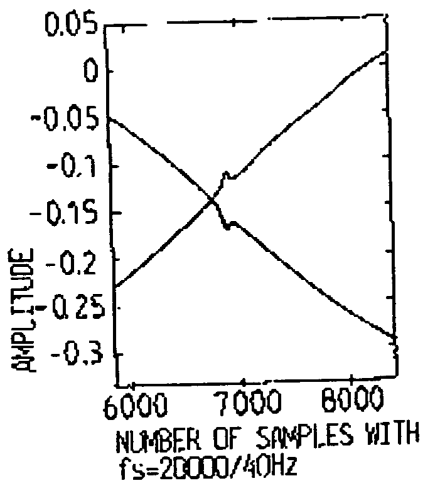

FIG. 8a

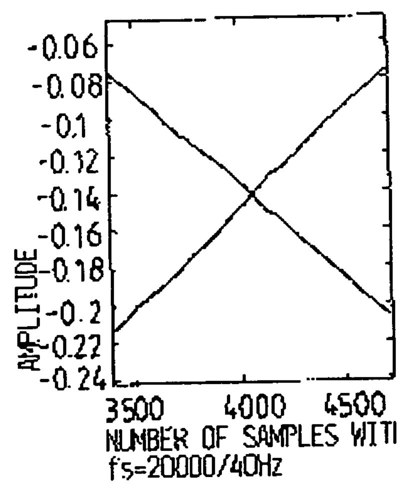

FIG. 8b

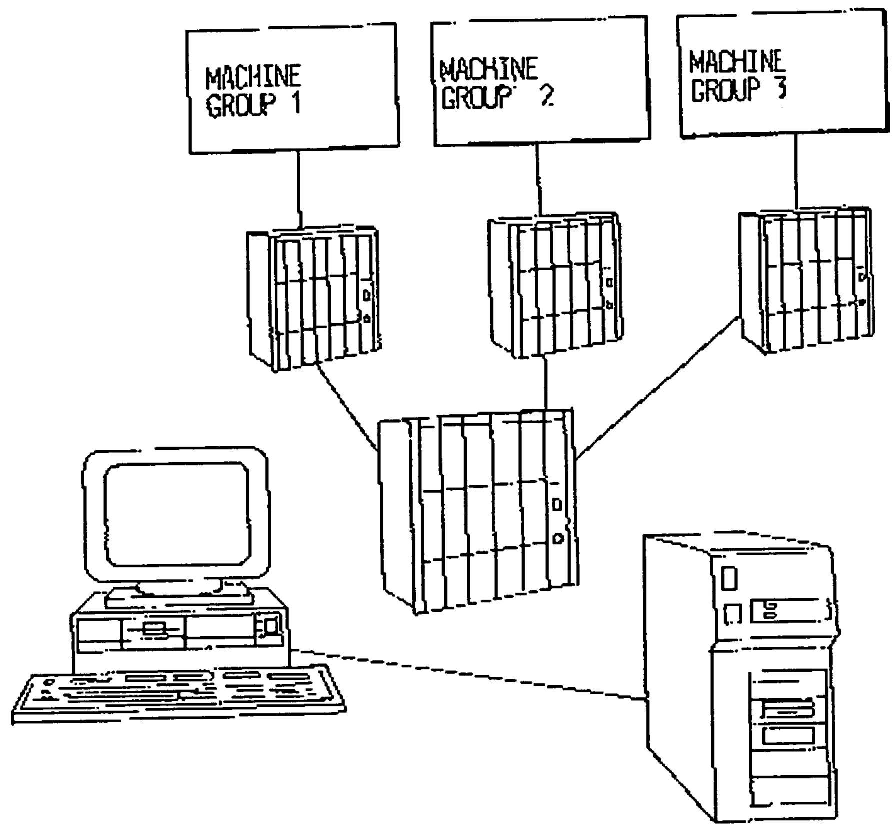

FIG.9